

RECENT B PHYSICS RESULTS FROM THE TEVATRON

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We review recent B physics results from the CDF and DØ experiments in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. Using a data sample of $1.4\text{--}6.0\text{ fb}^{-1}$ collected by the CDF II detector we present searches for New Physics in B_s sector and some competitive results with B -factories in the B/charm sector. In the first category we report the BR in $B_s \rightarrow J/\psi f_0(980)$ decays and the time-integrated mixing probability ($\bar{\chi}$) of B mesons. In the second category BR and A_{CP} in doubly Cabibbo-suppressed $B^\pm \rightarrow D^0 h^\pm$ decays and time-integrated CP violation in $D^0 \rightarrow h^+ h^-$ are presented.

1 Search for New Physics in B_s decays

Our current understanding of B_s physics, within the Standard Model (SM) and its sensitivity to New Physics (NP), is derived exclusively from the large Tevatron Run II data samples. One of the most interesting topics in this area is the measurement of B_s mixing phase, β_s . This phase is expected to be tiny in the Standard Model (SM):

$$\beta_s^{SM} = \arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*) \approx 0.02, \quad (1)$$

and it is unconstrained by the 2006 measurements of the B_s mixing frequency. Presence of NP can lead to large values of this phase which is not excluded experimentally yet.

The β_s^{SM} phase can be accessed through measuring the time evolution of flavor-tagged $B_s \rightarrow J/\psi\phi$ decays, or inclusively by measuring the anomalous mixing rate difference, A_{sl}^b , between B_s and \bar{B}_s . Both these methods are pursued at CDF and DØ.

Using 5.2 fb^{-1} and 6.1 fb^{-1} data samples, respectively, CDF and DØ have performed detailed angular analyses of the $B_s \rightarrow J/\psi\phi$ decays to disentangle their CP-even and CP-odd components. Their initial results indicate departure from SM by 0.8σ ¹ and 1.1σ ², calling for more scrutiny through independent measurements.

1.1 Measurement of $BR(B_s \rightarrow J/\psi f_0(980))$

A simpler way to measure β_s is through the study of $B_s \rightarrow J/\psi f_0(980)$, $f_0(980) \rightarrow \pi^+\pi^-$ decays. This is a pure CP-odd decay which can provide a clean measurement of β_s without a need for angular analysis. As a first step towards this CDF searched for this suppressed decay mode using 3.8 fb^{-1} data³, collected using a di-muon trigger.

The search for $B_s \rightarrow J/\psi f_0(980)$ decays proceeds through an initial loose selection of $\mu\mu\pi\pi$ candidates, followed by a Neural Network discrimination, based on kinematic variables,

track and vertex displacement and isolation, for efficient background suppression. An identical selection is used for the $B_s \rightarrow J/\psi\phi$ reference mode. A simultaneous log-likelihood fit to the signal and normalization modes yields $502 \pm 37(\text{stat.}) \pm 18(\text{syst.})$ $B_s \rightarrow J/\psi f_0(980)$ and $2302 \pm 499(\text{stat.}) \pm 49(\text{syst.})$ $B_s \rightarrow J/\psi\phi$ candidates.

Fig. 1 shows the invariant mass distribution of the $J/\psi\pi\pi$ candidate events. In addition

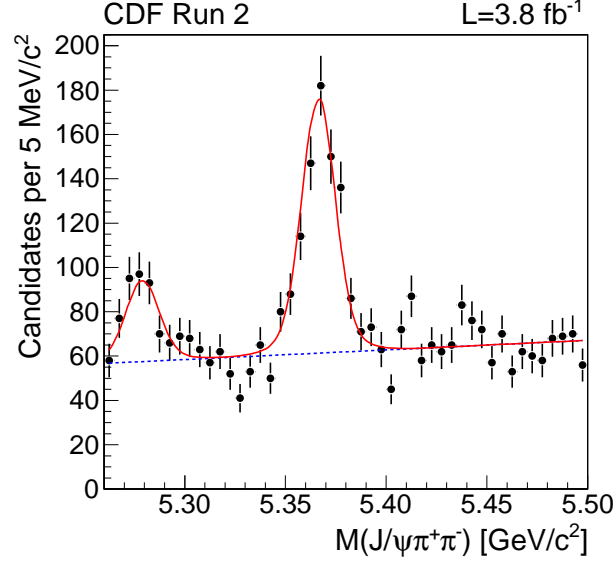


Figure 1: The invariant mass of $J\psi\pi\pi$ candidate events, measured by CDF with 3.8 fb^{-1} of data.

to the B_s peak with a significance of observation of 17.9σ , also seen is the $B^0 \rightarrow J/\psi\rho^0$ peak. The ratio between $BR(B_s \rightarrow J/\psi f_0(980), f_0(980) \rightarrow \pi\pi)$ and $BR(B_s \rightarrow J/\psi\phi, \phi \rightarrow KK)$ candidates, $R_{f_0/\phi}$, is $0.257 \pm 0.020(\text{stat.}) \pm 0.014(\text{syst.})$, resulting in a measurement of the branching ratio

$$BR(B_s \rightarrow J/\psi f_0(980), f_0(980) \rightarrow \pi\pi) = 1.63 \pm 0.12(\text{stat.}) \pm 0.09(\text{syst.}) \pm 0.50(\text{PDG}) \times 10^{-4}. \quad (2)$$

This is the most precise result obtained to date and confirms earlier results from Belle⁴ and LHC-b⁵.

1.2 Time-integrated mixing probability ($\bar{\chi}$) of B mesons

One of the most exciting results from Tevatron in recent times is the dimuon charge asymmetry measurement by the DØ Collaboration using muon pairs produced in semileptonic decays of b hadrons⁶. The asymmetry A_{sl}^b is defined as

$$A_{sl}^b = \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}, \quad (3)$$

where N_b^{++} and N_b^{--} are the numbers of same sign dimuon events produced due to the b hadrons decaying semileptonically, one before and the other after mixing. The quantity A_{sl}^b is expected to be approximately zero within the SM (\approx a few 10^{-4}), if mixing rates ($B \rightarrow \bar{B}$) and ($\bar{B} \rightarrow B$) are equal. Using a 6.1 fb^{-1} Run II data sample DØ measured $A_{sl}^b = (-0.957 \pm 0.251(\text{stat.}) \pm 0.146(\text{syst.}))\%$, which differs from the SM prediction⁷ of $A_{sl}^b(\text{SM}) = (-0.023^{+0.005}_{-0.006})\%$ at about 3.2σ , indicating an anomalously large B_s mixing phase.

The CDF Collaboration is pursuing an alternate path for independent verification of the interesting DØ result. The same sign (SS) and opposite sign (OS) muon impact parameter

(IP) distributions are fitted separately to disentangle the long-lived di-muon component that originates from B decays. The IP fitting method is a robust technique demonstrated well in the correlated $B\bar{B}$ cross-section measurement⁸.

As a first step towards an A_{sl}^b measurement, CDF further puts to test the IP fitting method and measures the time-integrated mixing probability, $\bar{\chi}$ ⁹, defined as

$$\bar{\chi} = \frac{\Gamma(B_{d,s}^0 \rightarrow \bar{B}_{d,s}^0 \rightarrow l^+ X)}{\Gamma(B_{all} \rightarrow l^\pm X)} = f_d \cdot \chi_d + f_s \cdot \chi_s \quad (4)$$

where $f_{d,s}$ are production fractions and $\chi_{d,s}$ are mixing probabilities of B_d and B_s mesons. The number of OS and SS muon pairs is measured and $\bar{\chi}$ is extracted from the ratio $R = [N(\mu^+\mu^+) + N(\mu^-\mu^-)]/N(\mu^+\mu^-)$. Fig. 2 shows the muon IP distributions for same sign dimuon pairs, with IP fit results for b , c , prompt and other sources. Using a 1.4 fb^{-1} data sample

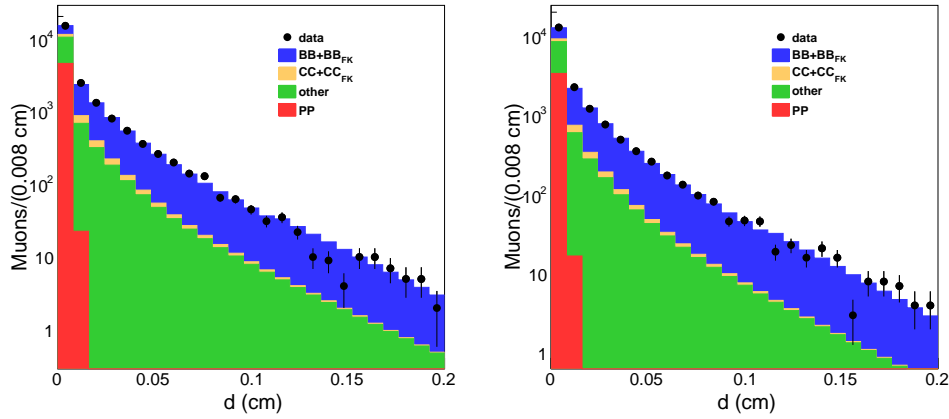


Figure 2: The muon impact parameter (IP) distributions are shown for same sign (a) $\mu^+\mu^+$ and (b) $\mu^-\mu^-$ pairs with IP fit results for b , c , prompt and other sources.

CDF measures an SS to OS ratio of $R = 0.467 \pm 0.011$, leading to $\bar{\chi} = 0.126 \pm 0.008$, in very good agreement with the LEP result of $\bar{\chi} = 0.126 \pm 0.004$. This validates the IP fitting method and presents an encouraging prospect towards CDF's future A_{sl} measurement.

2 New Tevatron results in the B /charm sector

Over the past decade, the Belle and BaBar B -factories have shaped up our knowledge of the $B_{u,d}$ and charm physics. With accumulation of large volume of Tevatron Run II data, the CDF and DØ experiments have caught up with, and in some cases surpassed, them in precision. In this section we present two new measurements from the CDF collaboration, competitive with the B -factories.

2.1 BR and A_{CP} in $B^\pm \rightarrow D^0 h^\pm$ decays

The branching fractions and searches for CP asymmetries in $B^\pm \rightarrow D^0 h^\pm$ decays allow for a theoretically clean measurement of γ , the least well constrained angle of the CKM matrix (known to 10-20° level). The proposed ADS method¹⁰ relies on interference between B^\pm decay modes proceeding through color allowed and suppressed modes followed by D^0 decay via doubly Cabibbo-suppressed (DCS) and Cabbibo-favoured modes, respectively, which can lead to large A_{CP} .

The DCS fraction and asymmetry in $B \rightarrow DK$ decays are defined as:

$$R_{ADS}(K) = \frac{BR(B^- \rightarrow [K^+\pi^-]_D K^-) + BR(B^+ \rightarrow [K^-\pi^+]_D K^+)}{BR(B^- \rightarrow [K^-\pi^+]_D K^-) + BR(B^+ \rightarrow [K^+\pi^-]_D K^+)} \quad (5)$$

$$A_{ADS}(K) = \frac{BR(B^- \rightarrow [K^+\pi^-]_D K^-) - BR(B^+ \rightarrow [K^-\pi^+]_D K^+)}{BR(B^- \rightarrow [K^-\pi^+]_D K^-) + BR(B^+ \rightarrow [K^+\pi^-]_D K^+)} \quad (6)$$

$$(7)$$

Similar quantities for pions, $R_{ADS}(\pi)$ and $A_{ADS}(\pi)$, can be defined. The experimental challenge is to suppress the combinatorial and physics backgrounds when extracting the highly suppressed DCS signal. Using 5 fb^{-1} of CDF Run II data, a likelihood fit combining mass and particle ID information is used to distinguish the signal ($D^0\pi$ and D^0K) modes from the background¹¹. Fig. 3 shows the invariant $K\pi\pi$ mass distributions for DCS signal modes separately for B^+ and B^- decays. The yields for π and K modes are 73 ± 16 and 34 ± 14 , respectively. The

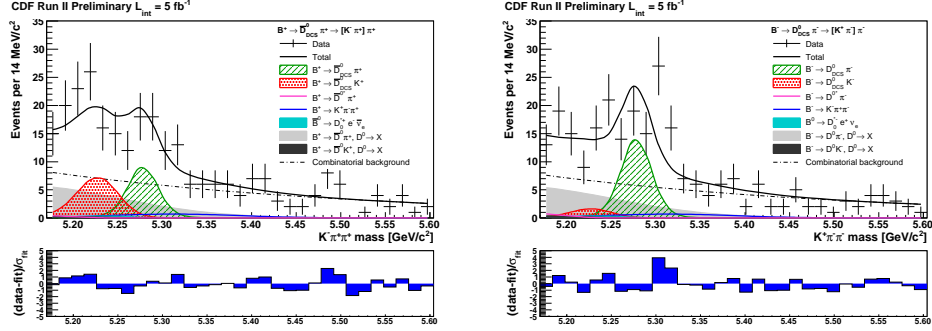


Figure 3: Invariant $K\pi\pi$ mass distributions for data and various background and signal contributions, separately for B^+ and B^- decays.

DCS fraction and asymmetry results for the Kaon mode are shown in Fig. 4, demonstrating good agreement with those from BaBar and Belle. This is the first application of the ADS method at

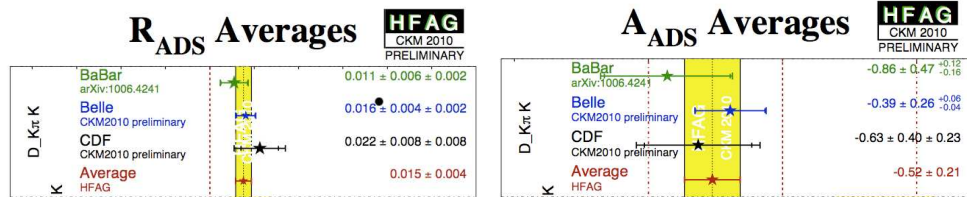


Figure 4: The DCS fraction and asymmetry results for the Kaon mode.

a hadron machine. CDF's new measurement of direct CP asymmetry for the DCS modes will be used in the future to extract γ .

2.2 Time-integrated A_{CP} in $D^0 \rightarrow h^+h^-$ decays

CP violation in the charm sector has been an area of great interest. Recent studies¹² have pointed out that, similar to D^0 oscillations, NP contributions could play a role in enhancing the size of CP violation in the charm sector. Since in SM there is negligible penguin contribution to the charm decays, an A_{CP} larger than $\sim 0.1\%$ would be a clear indication of NP. The relevant asymmetry is defined as

$$A_{CP}(h^+h^-) = \frac{\Gamma(D^0 \rightarrow h^+h^-) - \Gamma(\bar{D}^0 \rightarrow h^+h^-)}{\Gamma(D^0 \rightarrow h^+h^-) + \Gamma(\bar{D}^0 \rightarrow h^+h^-)}. \quad (8)$$

Using a 5.94 fb^{-1} data sample of self-tagged $D^{*\pm} \rightarrow D^0 \pi_s^\pm \rightarrow [h^+ h^-] \pi_s^\pm$ decays CDF extracts clean $D^0 \rightarrow h^+ h^-$ samples¹³. The asymmetry in $\pi\pi$ and KK samples is measured and corrected for the instrumental asymmetry using $K\pi$ samples, with and without the D^* tag. Fig. 5 shows the CP asymmetries for $D^0 \rightarrow \pi\pi$ and $D^0 \rightarrow KK$ decay modes and 68%-95% C.L. for their combination with the B -factory results. The resulting asymmetries are world's best:

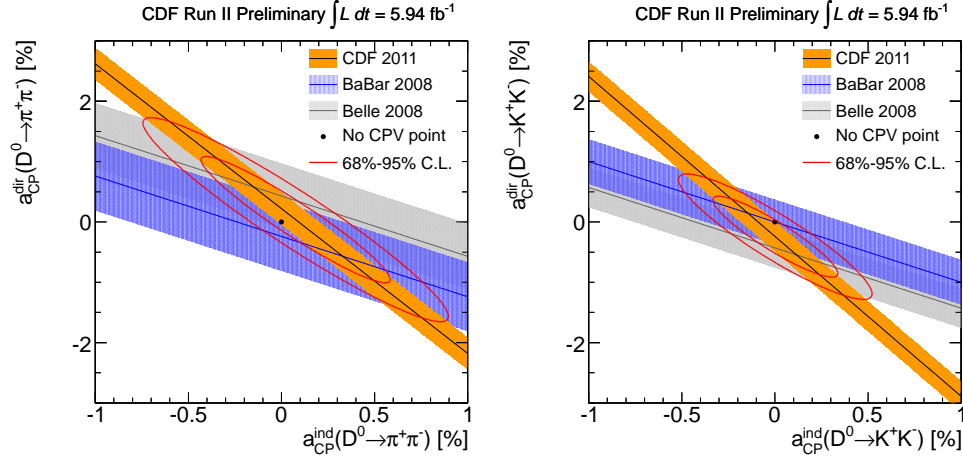


Figure 5: CP asymmetries in $D^0 \rightarrow \pi\pi$ and $D^0 \rightarrow KK$ decay modes and combination (contour) with the B -factory results.

$$A_{CP}(D^0 \rightarrow \pi^+ \pi^-) = [+0.22 \pm 0.24(stat.) \pm 0.11(syst.)]\% \quad (9)$$

$$A_{CP}(D^0 \rightarrow K^+ K^-) = [-0.24 \pm 0.22(stat.) \pm 0.10(syst.)]\% \quad (10)$$

and are compatible with Belle/BaBar 2008 results.

3 Conclusion

The Tevatron will continue to produce a steady flow of high luminosity data until Oct. 2011 when it is scheduled to shutdown permanently. Since mid-2000's the Tevatron experiments have emerged as leaders in the field of Heavy Flavor physics and would leave behind a rich legacy for current/future experiments through many landmark measurements. This article reviews a few of the interesting spring 2011 Heavy Flavor results from the Tevatron, which use a fraction of the accumulated data. With many more analyses in the pipeline and more data to be analyzed we look forward to challenging the SM predictions and constraining NP model parameters in the months and years to come.

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